Response of Young Apple Trees to Grass and Irrigation

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ABSTRACT. Ground covers and irrigation are important components of orchard floor management systems that affect fruit tree vigor and productivity. Three experiments were conducted in a greenhouse to determine the relative water use of candidate ground covers (roughstalk bluegrass, RB, *Poa trivialis*), Chewing's fescue (CH, *Festuca rubra* subsp. *commutata* Gaudin), creeping red fescue (RF, *Festuca rubra* L. subsp. *rubra*), tall fescue (TF, *Festuca arundinacea* Schreber, Fawn), and perennial ryegrass (PR, *Lolium perenne* L., 'Saint') and the response of apple trees to those ground covers and to drip irrigation applied at two soilless substrate depths. Grass ground covers with large and deep root systems (TF and PR) used more water than a shallow-rooted grass (RB) and leaf water potential decreased more rapidly in apple trees grown with TF than RB when irrigation was withheld. Although apple tree shoot growth was greater with shallow- than deep-rooted grass, photosynthesis, transpiration, and root biomass distribution were not differentially affected by grass type. When grown with RB or TF, irrigation depth affected apple tree growth. During the first season in the greenhouse, deep irrigation at 37 cm depth increased

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apple root length density near emitters but shoot growth was less in apple grown with deep irrigation compared with apple grown with surface irrigation (0 cm) and with split irrigation at 0 and 37 cm. During the second season in the greenhouse, deep irrigation was beneficial to trees grown with grass that had large, deep root systems (TF) but it did not completely overcome interference effects of grass on apple trees, regardless of grass root system size or distribution. The results indicate that grasses with shallow root systems may be grown beneath apple trees and that split irrigation at two depths can provide flexibility that is necessary for water management of ground covers and apple trees.

KEYWORDS. Ground cover, orchard floor management, managed competition

INTRODUCTION

The floor of fruit tree orchards must be managed to regulate weeds, insects, small mammals, disease, soil fertility, water availability, and the potential for erosion and pollution. Continuous, clean cultivation of the orchard floor aerates the soil and eliminates competition, but loss of organic matter, breakdown of soil structure, increased potential for erosion, and destruction of shallow tree roots will occur (Haynes, 1980; Hogue and Neilsen, 1987; Skroch and Shribbs, 1986). Inclusion of preemergence herbicides and mechanical tillage to eliminate weeds also may reduce soil structure, fertility, and orchard productivity compared with “living” and straw-hay mulches (Merwin et al., 1994) and killed sod systems (Glenn and Welker, 1989). Ground cover vegetation increases soil organic matter, structure, and water penetration but ground covers must be managed to control competition and reduce pests that are associated with ground covers.

Broad leaved weeds may host insects that can cause catfacing damage to the exterior of fruit or that disrupt pollination by blooming at the same time as fruit trees (Atanassov et al., 2002; Killian and Meyer, 1984; Parker, 2003; Pickel et al., 2002). Broad-leaved weeds also may serve as alternative hosts for viruses, which can be transmitted to fruit trees by nematodes and insects (Duffus, 1971; Powell and Forer, 1982; Skroch and Shribbs, 1986). Grass in combination with management practices such as mowing can suppress broadleaved weeds and grass cover can help protect soil quality (Tworkoski and Glenn, 2001). Grasses generally do not serve as hosts to crop-injuring pests although some grasses can compete with fruit trees.

Grass competition reduced growth of young and mature peach (*Prunus persica* (L.) Batsch.) trees (Glenn and Welker, 1991; Parker and Meyer, 1996; Tworkoski, 2000; Tworkoski and Glenn, 2001). As a permanent and complete ground cover, orchardgrass (*Dactylis glomerata* L.) reduced peach yield by up to 37% but 'Linn' perennial ryegrass (*Lolium perenne* L.) did not reduce yield in 8-year-old peach trees (Tworkoski and Glenn, 2001). Shallow-rooted grasses such as Kentucky bluegrass (*Poa pratensis* L.), annual bluegrass (*Poa annua* L.), fescue (*Festuca elatior* L.), and orchardgrass deplete less moisture from an orchard than deep-rooted sods (Hogue and Neilsen, 1987; Skroch and Shribbs, 1986). Since ground covers can exploit the upper soil it is possible that a grass with less roots or shallower rooting habit might be less competitive with a fruit tree. In addition, irrigation beneath the root depth of grass could reduce competition for water between the tree and the ground cover.

Irrigation can increase crop yield and many orchards are irrigated, even in the eastern United States where rainfall tends to be adequate for tree growth. It is possible that irrigation can compensate to some extent for grass competition (Merwin and Ray, 1997). When applied to the soil surface, irrigation provides water both to the crop and to ground cover. Subsurface irrigation could selectively provide water to deep roots, such as those of fruit trees, without supplementing water to shallow-rooted ground cover. It may be possible to combine grass ground cover with deep irrigation in an orchard floor management system to provide edaphic resources to the fruit tree while suppressing weeds through managed competition with grass.

Before implementing field tests, information is needed to identify candidate grasses with morphological and physiological traits that reduce competition between grass and fruit trees. A desirable ground cover would suppress weeds and compete little with fruit trees. The current research dealt with two related components of an orchard floor management system, ground cover, and irrigation, which were manipulated in pots in a greenhouse. The objectives of this research were to (1) determine the water use and competitiveness of five grasses and apple trees and (2) determine the effects of surface and deep irrigation in combination with a strong and a weak grass competitor on apple tree growth.

MATERIALS AND METHODS

Experiment 1: Water Use by Different Grasses

Seed of five candidate grasses, roughstalk bluegrass (RB, *Poa trivialis*), Chewing's fescue (CH, *Festuca rubra* subsp. *commutata* Gaudin), creeping red fescue (CR, *Festuca rubra* L. subsp. *rubra*), tall fescue (TF, *Festuca arundinacea* Schreber, Fawn), and perennial ryegrass (RG, *Lolium perenne* L., Saint) were obtained from Ernst Conservation Seed (9006 Mercer Pike, Meadville, Pa.). These grasses were selected based on availability, extension recommendations, and their range of vigor and rooting depths (Tworkoski and Glenn, 1996; Vossen and Ingals, 2002; Willmott et al., 2000). Grasses were planted in PVC tubes (1 m tall × 10-cm diam.) with Metro Mix 510 (The Scotts Co., Marysville, Ohio) on 25 Jul. 2005 at a rate of 1 g seed per pot. Pots were watered each day to field capacity until one month after seed germination when water was withheld from three of the six reps. Three reps continued to receive daily watering. Water loss in the non-irrigated pots was used to gauge the relative water use by each grass. Total weight of grass and tubes were measured every 2 to 3 days for one month when all grass and soilless substrate were harvested and weighed. At harvest, each pot was split longitudinally and divided into 20-cm depths. Roots were isolated by rinsing with water. Fresh (fw) and dry weight (dw) of soilless substrate was measured for each 20-cm depth (5 depths per tube) and gravimetric soilless substrate moisture was calculated from the difference between fw and dw, divided by dw. Average daily water use was estimated by regression analysis. The grass water use experiment had a factorial design with five grasses and two water treatments, each replicated three times. Treatment effects were evaluated by the general linear model procedure and means were separated by the LS Means procedure (SAS, 2001).

Experiment 2: Apple Tree Response to Grass Competition and to Withholding Irrigation

'Enterprise' apple trees (approximately 1.3 cm diam.) on Budagovsky.9 (B.9) rootstock were obtained from Adam's County Nursery (Aspers, Pa.), and planted in similar pots and media used in Experiment 1. Pots were constructed from three PVC tubes that were split longitudinally and reassembled with duct tape along the seams (1 m tall × 20-cm diam.). Trees were planted on 27 Jan. 2006, watered to field capacity, and seed of five grasses used in Experiment 1 were sown in pots with trees (1 g/pot) on 1 Feb. 2006. Five pots did not receive grass. Natural sunlight was supplemented, and photoperiod was maintained at 16 h with high-pressure sodium lights (580 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetically active radiation; 23 ± 5°C). Trees were feathered in the nursery and in the greenhouse they were pruned to three lateral branches per tree and shoot elongation of each branch was measured each week. During the first month in the greenhouse, trees were watered to field capacity, during the second month trees received a fixed quantity of water based on water use estimates, and during the third month all water was withheld. Applying fixed amounts of water or withholding irrigation enabled comparison of the competitiveness of each grass with the apple trees.

One month after planting, pots were watered to field capacity and then weighed over several days to estimate water use by trees and grass. Average daily water use was estimated by regression analysis of water loss over time. Weights of trees grown in bare soilless substrate indicated that average tree water use was 220 mL/pot/day. Gravimetric measurements from Experiment 1 indicated that the water use of grass, averaged for all species and similar environmental conditions, was 90 mL/pot/day. The average daily water use of grass plus tree was estimated to be 310 mL/pot/day. It was assumed that daily water use of trees plus grass would vary each day but that, on average, 310 mL/pot/day would provide adequate water for trees plus some grasses while water would be limiting for trees grown with grasses that required more water. Water was applied to the soilless substrate surface at the estimated average use rate (310 mL/day) from 1 Mar. to 4 Apr. 2006. On 5 Apr. 2006, trees were watered once to field capacity and then irrigation was stopped. Prior to watering to field capacity and during the subsequent drying period, leaf water potential (Soil Moisture Equipment Corp., Santa Barbara, Calif.), transpiration, stomatal conductance, and C assimilation (CIRAS-1, PP Systems, Haverhill, Mass.) were measured daily. Water status measurements continued until leaves wilted, 14 Apr. for the first tree, and the last tree was measured on 28 Apr. On 8 May 2006, roots were harvested by cutting the tube longitudinally, separating the soilless substrate column into 20-cm segments, and separating the apple roots from the grass roots. Roots were dried for 3 days at 80°C before weighing. Relative water content of plant parts was calculated as the difference of fw and dw divided by dw. The experiment was completely randomized with six grass treatments and five replications. Treatment effects were evaluated by the general linear model procedure and means were separated using the Duncan's multiple range test (SAS, 2001).

Experiment 3: Apple Tree Response to Grass Competition and to Irrigation at Two Soilless Substrate Depths

'Autumn Rose Fuji'/B.9 (1.3 cm diam.) were obtained from Adams County Nursery and were planted on 14 Aug. 2006 into pots and media that were described previously. Trees were pruned to three lateral branches per tree and shoot elongation of each branch was measured each week. Natural sunlight was supplemented, and photoperiod was maintained at 16 h with high-pressure sodium lights (580 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetically active radiation; 23 ± 5°C). Grass seed (1 g/pot) from RB and from TF were planted in 18 pots (9 pots/grass) with trees on 14 Sept. 2006. Nine pots did not receive grass. All trees were watered to field capacity until irrigation treatments were installed. On 17 Oct. 2006, irrigation emitters were placed in three possible soilless substrate depth combinations: surface only, 37-cm depth only, or surface plus 37-cm depth. For 37-cm depth irrigation, drip irrigation emitters were inserted horizontally through the side of a pot. For all irrigation locations, water was provided at a rate of 310 mL/tree/day, an average rate that was determined to be used by trees plus ground covers based on gravimetric measurements taken in Experiment 2 and confirmed during Sept. 2006 with the trees used in Experiment 3. In addition to the three irrigation treatments, three trees received no grass and were watered to field capacity for comparison. Shoot elongation slowed by 23 Jan. 2007 (end of the first season) and elongation resumed 15 May 2007 (beginning of the second season). During the second growing season irrigation was supplemented with fertilizer (20N-8.8P-16.6K), applied in the irrigation (0.3 $g \cdot L^{-1}$). The experiment was a factorial design composed of three ground cover and three irrigation treatments replicated three times. Growth, leaf water potential, transpiration, stomatal conductance, and photosynthesis were measured as described previously. Vigor of leaves was estimated based on intensity of green color with a SPAD-502 chlorophyll meter (Minolta Camera Co., Ltd., Osaka, Japan). Root length density (RLD, root length in cm cm^{-3}) of apple and grass were measured at 0 and 37 cm on 21 Feb. 2007. A cylindrical soil probe (62.8 cm^3) was inserted through access holes in the side of a pot and a soilless substrate plus root sample was extracted. New soilless substrate was used to fill the resulting space and the access holes were sealed. The grass root was separated from apple root and root lengths were measured with a root imaging device (CID, Inc., Vancouver, Wash.).

On 10 Sept. 2007, RLD and specific root length (SRL, g cm^{-1}) were measured for apple roots at each 20-cm soilless substrate depth interval by sampling soilless substrate and roots with a soil probe (62.8 cm^3) that was inserted horizontally into each pot. New soilless substrate was used to fill the resulting space and the access holes were sealed. Soilless substrate moisture content was determined as the difference in soilless substrate fw and dw divided by dw. On 12 Sept. 2007 trees were watered to field capacity and then irrigation was stopped. During the subsequent drying period, leaf water potential was measured every 2 days until leaves wilted. Time to leaf wilt was determined and root biomass distribution of apple and grass were measured in Oct. 2007, as described for Experiment 2. The grass and irrigation experiment had a factorial design with three grasses and three water treatments, each replicated three times. Treatment effects were evaluated by the general linear model procedure and separated by the LS Means procedure (SAS, 2001).

RESULTS

Experiment 1: Water Use by Different Grasses

Tall fescue and RB daily water use was greatest and least, respectively, during the 30-d period when water was withheld (Table 1). Tall fescue used 2.7 times more water than RB; 1.8 times more water than CH; and nearly 1.4 times more water than CR and RG. In general, grass depleted more water from the top 20 cm of soilless substrate than from soilless substrate at increasing depths but differences in soilless substrate water depletion among grass types occurred with increasing depths. At soilless substrate depths below 40 cm, RB depleted seven to nine times less water than TF or RG when water was withheld. At increasing soilless substrate depths, reduced moisture coincided with grasses that had greater root abundance (Table 2). Few RB roots at depths below 40 cm probably contributed to less water uptake from deep soilless substrate and to less water use, overall (Table 2). Based on the water use rate differences among the grass types, we expected water to become limiting and grass to affect apple tree growth in the following order when a constant amount of water is applied to each apple tree: TF > CR = RG > CH > RB.

TABLE 1. Grass daily water use, average total soilless substrate moisture and soilless substrate moisture content at five depths beneath five grass cultivars that were grown with irrigation for 30 d and then half with continued irrigation and half with drought for 30 d in Experiment 1

	Daily water use[z] (mL)	Total soilless substrate moisture (% dw)		Soilless substrate depth (cm) / Soilless substrate moisture (% dry weight)									
				0–20		20–40		40–60		60–80		80–100	
		I[y]	D	I	D	I	D	I	D	I	D	I	D
Roughstalk bluegrass	51.1 d*	260 a	272 a	211 a	32 a	230 a	158 a	231 a	197 a	260 a	268 a	372 a	272 a
Chewings red fescue	74.8 c	216 b	198 ab	78 b	21 b	160 b	73 b	233 a	179 a	284 a	229 a	326 a	199 ab
Creeping red fescue	91.3 b	190 b	220 a	65 b	26 ab	80 c	27bc	260 a	60 b	263 a	129 b	283 a	220 a
Tall fescue	136.1 a	73 c	14 c	78 b	26 ab	117 bc	24bc	198 ab	23 b	213 a	39 c	249 ab	43 bc
Perennial ryegrass	95.4 b	171 b	42 bc	43 b	28 ab	50 c	19 c	102 b	22 b	89 b	21 c	82 b	14 c

[z]Estimated by the slope of the line obtained by regressing daily weight loss over 30 d when irrigation was withheld.
[y]I designates grass that was irrigated for 60 d and D designates grass that was irrigated for 30 d, followed by withholding water (drought) for 30 d.
*Within each column, means followed by the same letter do not differ at the 0.05 level of significance.

TABLE 2. Total weight and distribution of grass root biomass at five depths beneath five grass cultivars that were grown with irrigation for 30 d and then half with continued irrigation and half without water for 30 d in Experiment 1

	Total root dry weight (g)		Soilless substrate depth (cm) Root dry weight (g)									
			0–20		20–40		40–60		60–80		80–100	
	I[z]	D	I	D	I	D	I	D	I	D	I	D
Roughstalk bluegrass	14.29 b*	7.58 b	13.3 b	7.5 bc	0.9 a	0.1 b	0.1 b	0.0 b	0.0 b	0.0 c	0.0 b	0.0 b
Chewings red fescue	35.89 ab	5.64 b	33.3 ab	4.7 c	2.4 a	0.8 ab	0.1 b	0.1 b	0.0 b	0.0 c	0.0 b	0.0 b
Creeping red fescue	42.11 ab	10.65 b	36.6 ab	6.5 c	3.9 a	2.1 ab	1.3 a	1.4 ab	0.2 b	0.6 c	0.1 b	0.1 b
Tall fescue	47.44 a	20.03 a	39.8 a	10.3 ab	2.8 a	2.8 ab	2.0 a	2.6 a	1.3 a	3.1 a	1.6 a	1.2 a
Perennial ryegrass	28.95 ab	17.81 a	24.0 ab	11.3 a	3.1 a	2.9 a	1.4 a	1.8 ab	0.4 b	1.7 b	0.1 b	0.2 b

[z]I designates grass that was irrigated for 60 d and D designates grass that was irrigated for 30 d, followed by withholding water (drought) for 30 d.
*Within each column, weights followed by the same letter do not differ at the 0.05 level of significance.

Irrigation and grass species interacted to affect shoot (data not shown) and root dry weight (Table 2). Withholding irrigation reduced root dry weights of all grasses; root dry weight was reduced by 46.8% and 57.6% in RB and TF, respectively (Table 2). Root dw of TF was 3.3 and 2.6 times greater than RB under full and withheld irrigation, respectively.

Experiment 2: Apple Tree Response to Grass Competition and to Withholding Irrigation

Total apple shoot growth at 79 days after planting did not differ when trees were grown with CN, RB, and RG (Fig. 1). Total shoot growth of apple grown with CH and with TF was less than all other treatments. As predicted from Experiment 1, grasses that were among the least and most suppressive to apple shoot growth were RB and TF, respectively (Fig. 1).

With increased time after cessation of irrigation (63 days after planting), differences in leaf water potential occurred among apple trees grown with different grasses (Fig. 2). Leaf water potential differed significantly

FIGURE 1. Shoot elongation of 'Enterprise'/B.9 apple trees in a greenhouse grown with five grass cultivars. Trees were watered to field capacity for the first 35 days after planting and then received 310 mL water per day until 63 days after planting when trees were watered once to field capacity and irrigation was withheld. At 79 days after planting, means followed by the same letter do not differ at the 0.05 level of significance. CN = control without grass, RB = roughstalk bluegrass, CH = chewings red fescue, CR = creeping red fescue, TF = tall fescue, and RG = perennial ryegrass.

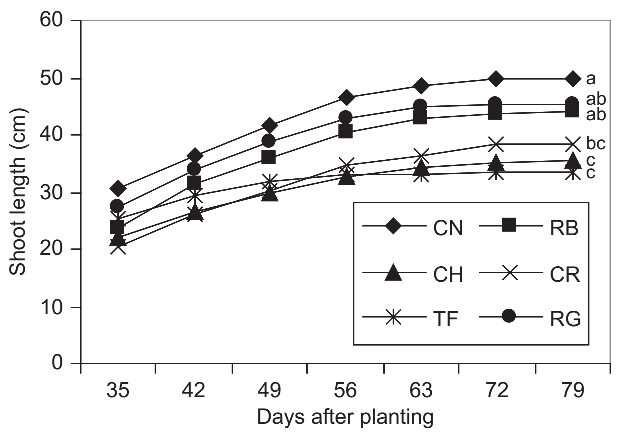
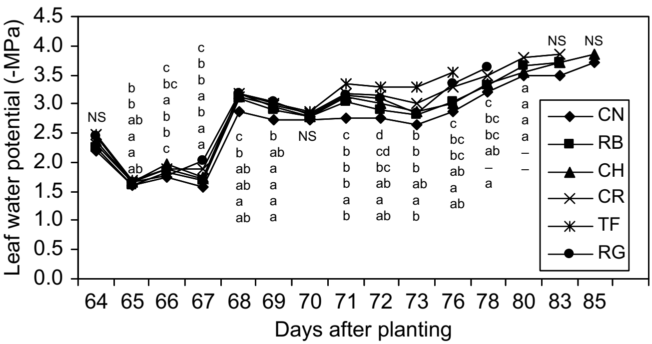


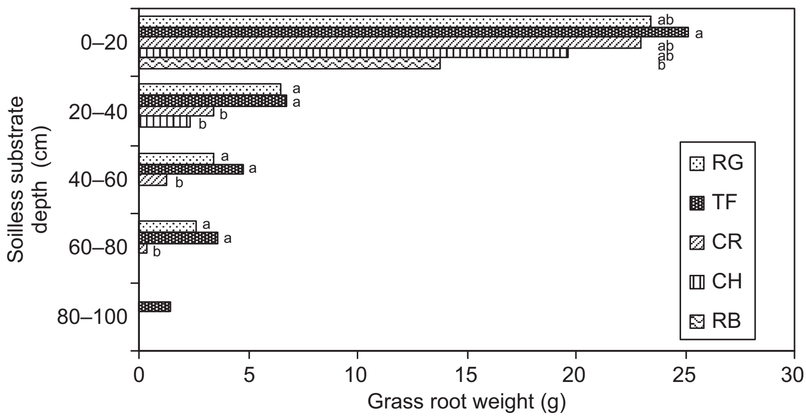
FIGURE 2. Leaf water potential of ‘Enterprise’/B.9 apple trees in a greenhouse grown with five grass cultivars. Trees were watered to field capacity for the first 35 days after planting and then received 310 mL water per day until 63 days after planting when trees were watered once to field capacity and irrigation was withheld. CN = control without grass, RB = roughstalk bluegrass, CH = chewings red fescue, CR = creeping red fescue, TF = tall fescue, and RG = perennial ryegrass. Within each day after planting, mean separation of leaf water potential measurements are presented for CN, RB, CH, CR, TR, and RG (top-to-bottom); within any day after planting, grass treatments followed by the same letter do not differ at the 0.05 level of significance.

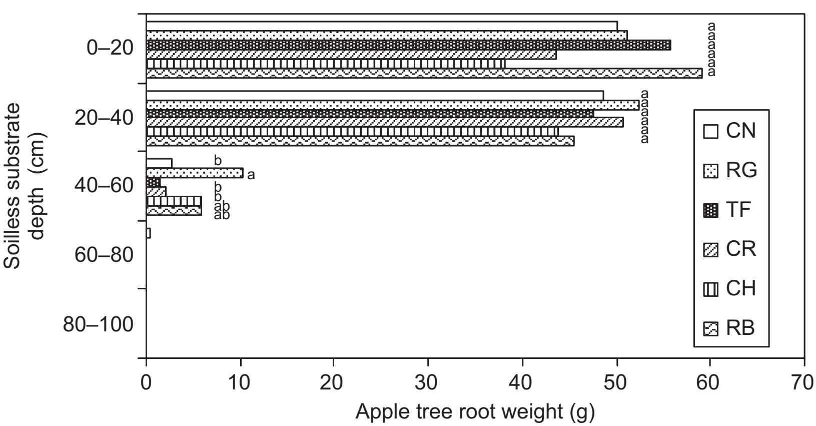


due to grass on all days except 64 and 70 days after planting (Fig. 2). Leaf water potential was most negative in trees grown with TF and least negative without grass or with RB on 65, 68, 71, 72, 73, 76, and 78 days after planting. Other grass species effects on leaf water potential were intermediate and not consistently ordered between TF and RB. Grass did not induce significant differences in gas exchange in apple trees while withholding irrigation (data not shown). Transpiration, stomatal conductance, and photoassimilation of apple trees decreased over time and followed similar patterns regardless of grass cover (data not shown).

The greatest and least grass root weight at all soilless substrate depths tended to be TF and RB, respectively (Fig. 3). At the 0 to 20-cm depth, root weight of TF was twice that of RB and RB roots were extremely sparse at depths below 20 cm. Most grass root weight occurred in the upper 20 cm of soilless substrate, 99% and 60% for RB and TF, respectively. Compared with control trees, apple root weight distribution was not affected by grass except with RG at the 40- to 60-cm depth (Fig. 3). Relative water content, expressed as a percent of dry weight, of apple

FIGURE 3. Root weight distribution at five soilless substrate depths of grass (top) and 'Enterprise'/B.9 apple trees (bottom) that were grown together for 85 d. Trees were watered to field capacity for the first 35 days after planting and then received 310 mL water per day until 63 days after planting when trees were watered once to field capacity and irrigation was withheld. Within each soilless substrate depth, means followed by the same letter do not differ at the 0.05 level of significance. CN = control without grass, RB = roughstalk bluegrass, CH = chewings red fescue, CR = creeping red fescue, TF = tall fescue, and RG = perennial ryegrass.





leaves and new shoots was not affected by grass (data not shown). However, the number of days to apple leaf wilt was affected by grass with CN, RB, CH, CR, RG, and TF wilting at 82.6, 82.0, 83.0, 81.2, 77.8, and 76.8 days after planting, respectively (Fig. 2). Apple trees grown with RG and TF wilted at the same time statistically, which was faster than wilt of trees grown with CH, CN, and RB. Total apple shoot weights and dry weight distribution were not affected by grass (data not shown). However, total new shoot dry weights were affected by grass. Greatest new shoot growth was in trees grown without grass (36.0 g), RB (31.3 g), and RG (30.1 g), and least shoot growth was with TF (22.7 g).

Experiment 3: Apple Tree Response to Grass Competition and to Irrigation at Two Soilless Substrate Depths

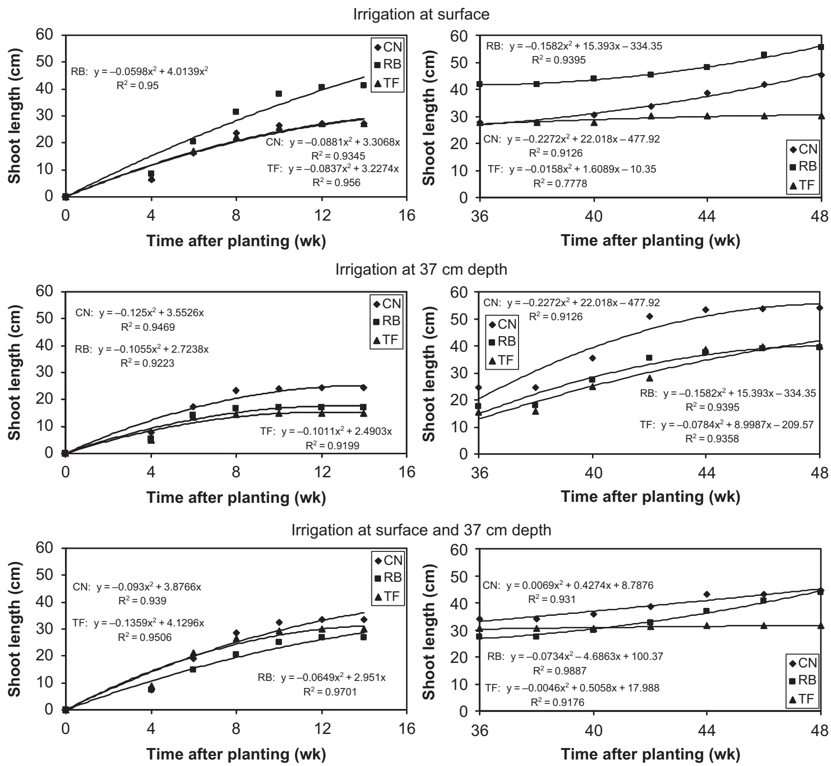
During the first growing season, trees generally grew least when irrigated only at the 37-cm depth (Fig. 4). Greatest apple shoot elongation resulted from top irrigation plus RB and least growth from deep irrigation plus TF (Fig. 4). During the second growing season of Experiment 3, irrigation location and grass cover interacted so that apple shoots grew in the presence of TF only when irrigated at the 37-cm depth (Fig. 4). Split irrigation at surface and the 37-cm depth provided half the water as the 37-cm depth irrigation to deep roots and split irrigation did not overcome the growth competitive effects of TF (Fig. 4). During the second season, TF generally suppressed apple shoot elongation, whereas RB did not (Fig. 4).

Trees grown with surface and deep irrigation and trees grown with grass competition had the greatest negative leaf water potential at 8 weeks after planting (Table 3). Irrigation position and grass did not affect photosynthesis or SPAD measurements at 8 weeks after planting (Table 3). However, by 42 weeks after planting, apple trees that received deep irrigation and fertilizer had greater photosynthesis and SPAD levels than trees receiving the other irrigation and fertilizer treatments (Table 3). Deep irrigation and fertilization increased the RLD of apple in 40- to 60-cm depths where water was applied by 48 weeks after planting (Table 4). By 48 weeks after planting, TF decreased apple RLD at the 40- to 60-cm depth, whereas RB did not (Table 4).

DISCUSSION

Sustainable orchard management requires balance of inputs such as pesticides, fertilizers, and irrigation, with outputs such as profitable yield of a quality crop and a healthy, productive environment. Understory vegetation (USV) of orchards can reduce growth and yield in fruit trees

FIGURE 4. Shoot length of 'Fuji'/B.9 apple trees grown with three ground covers (none, roughstalk bluegrass, and tall fescue; CN, RB, and TF, respectively) and three irrigation depths (surface, deep, surface and deep; top, middle, and bottom, respectively). Shoot length during the first growing season are presented in graphs on left and second season growth in graphs on the right. Based on analysis of variance grass, irrigation, time, and the grass-by-irrigation interaction significantly affected shoot length at the 0.05 level of significance.



(Foshee et al., 1997; Glenn and Welker, 1989; Layne et al., 1981; Tworkoski and Glenn, 2001; Welker, 1984) by competing for water (Hogue and Neilsen, 1987; Skroch and Shribbs, 1986). Herbicides and cultivation often are used to reduce or eliminate USV, although USV may improve soil health (Glenn and Welker, 1989; Kenworthy, 1953; Welker and Glenn, 1988) and provide habitat for beneficial insects (Atkinson and White, 1981; Brown, 2001, 2002). A strategy of matching USV species,

TABLE 3. Physiological responses of ‘Fuji’/B.9 apple trees grown with three irrigation locations and three grass treatments that were sampled during the first and second growing seasons in the greenhouse (8 and 42 weeks after planting, respectively) in Experiment 3

Treatments		Weeks after planting					
		Leaf water potential (MPa)		Spad reading		Photosynthesis ($\mu mol\ CO_2/m^2/s$)	
		8[z]	42	8	42	8	42
Irrigation location	Surface (S)	1.36 b	0.71 a	33.2 a	24.9 b	10.5 a	12.1 b
	37-cm Depth (D)	1.47 b	0.48 a	35.1 a	45.7 a	12.1 a	18.5 a
	S + D	1.51 a	0.78 a	34.5 a	21.0 b	12.0 a	14.7 b
Grass	Tall fescue	1.53 a	0.80 a	36.6 a	29.8 a	11.0 a	14.7 a
	Roughstalk bluegrass	1.56 a	0.66 a	32.7 a	29.0 a	12.0 a	15.5 a
	None	1.37 b	0.51 a	33.8 a	29.7 a	11.5 a	15.1 a
	P> f						
Grass (G)		0.01	0.14	0.56	0.89	0.65	0.90
Irrigation location (I)		0.01	0.11	0.91	0.01	0.29	0.01
G × I		0.88	0.06	0.48	0.10	0.94	0.44

[z]Within each column and main treatment effect, means followed by the same letter do not differ at the 0.05 level of significance.

TABLE 4. Root length density of 'Fuji'/B.9 apple trees grown with three irrigation locations and three grass treatments that were sampled at two depths at the beginning and end of the second growing season in the greenhouse (36 and 48 weeks after planting, respectively) in Experiment 3

Treatments		Root length density (mm / cm^3)					
		Soilless substrate depth (cm)					
		Grass		Apple			
		36 WAP		36 WAP		48 WAP	
		0–20[z]	40–60	0–20	40–60	0–20	40–60
Irrigation location	Surface (S)	1.4 a	0.3 a	4.0 a	1.7 b	6.3 a	2.8 b
	37-cm Depth (D)	2.1 a	0.7 a	3.6 a	4.4 a	4.6 a	4.9 a
	S + D	1.6 a	0.3 a	4.1 a	2.7 ab	3.1 a	2.6 b
Grass	Tall fescue	5.5 a	2.1 a	3.9 a	2.1 a	2.2 a	1.5 b
	Roughstalk bluegrass	0.3 b	0 b	5.1 a	3.4 a	5.8 a	4.6 a
	None	0 b	0 b	2.9 a	3.0 a	6.8 a	4.2 a
	P > f						
Grass (G)		0.01	0.01	0.26	0.41	0.12	0.01
Irrigation location (I)		0.35	0.72	0.96	0.07	0.28	0.01
G × I		0.52	0.87	0.20	0.76	0.60	0.12

[z]Within each column and main treatment effect, means followed by the same letter do not differ at the 0.05 level of significance.

based on rooting depth, with irrigation at different depths could offer alternative tools for sustainable orchard management. Inherent to this strategy is niche separation, with apple roots exploiting water that is less available to USV. In this experiment we distinguished competitiveness of designated USV and determined whether selective placement of irrigation and fertilizer could overcome the competitive interaction between USV and apple trees.

Five grasses were tested as candidate USV because grasses, in general, are less suitable habitat than broad-leaved plants to numerous pests (Alston, 1994; Ames and Kuepper, 2000; Atanassov et al., 2002; LaRue and Johnson, 1989). A wide range of water use was measured from 51 to 136 mL/pot/day for RB and TF, respectively. Grasses with intermediate root depths (CR, RG, and CH) were also intermediate in water use. Grass with the greater water use had deeper roots, which utilized water from greater soilless substrate depths. For example, TF had the greatest root mass and greatest soilless substrate water depletion at depths below 20 cm (Fig. 3; Tables 1 and 2). These results support those of Hogue and Neilsen (1987) and Skroch and Shribbs (1986) that shallow-rooted bluegrass (*Poa* spp.) and fescue (*Festuca* spp.) deplete less moisture from an orchard than deep-rooted grasses. Our results demonstrate that water depletion from the top 20 cm of soilless substrate was similar for all grasses regardless of rooting depth.

Apple trees were grown with the five candidate USV to determine if the relative ranking of water use and rooting depth of the grasses were predictive of the growth and physiological responses of apple trees that were grown with those grasses and with limiting water. Tall fescue induced the greatest negative leaf water potential and inhibited growth most in apple trees. The USV with the smallest and most shallow root system, RB, used the least water and trees grown with RB did not differ from trees grown without USV. The other USV candidates had intermediate effects on apple leaf water potential and growth. Because of the difficulty of extrapolating greenhouse results to the field, we cannot be certain that the relative ranking of the grass's impact on tree growth and water status will have similar effects in an orchard. However, previous work demonstrated that fruit tree growth depends on USV. As a permanent and complete ground cover, orchardgrass reduced peach yield by up to 37%, but 'Linn' perennial ryegrass did not reduce yield in 8-year-old peach trees (Tworkoski and Glenn, 2001). Interestingly, during the first growing season of Experiment 3, greatest apple shoot growth resulted from surface irrigation only in combination with RB (Fig. 4). It is possible that the RB enabled water penetration and served as mulch.

Grasses can induce decreased root growth and different distribution of roots of fruit trees. Root density of peach and *Prunus avium* L. trees decreased in sod and grew deeper and in greater number beneath shallow-rooted grass (Dawson et al., 2001; Glenn and Welker, 1991; Parker and Meyer, 1996, Tworkoski, 2000). In the second experiment of the current study, total apple root biomass distribution was not differentially affected by grasses with different rooting depths. However, in the third experiment, RLD changed with time, increasing with soilless substrate depth in response to grass and irrigation treatments (Table 4). This change likely was due to tree root acclimation to soilless substrate conditions. In the third experiment of the current study, shallow grass roots combined with irrigation and fertilizer at the 37-cm depth stimulated the increase in apple RLD at the 20- to 40-cm depth. Grass-induced distribution of fruit tree roots may be exploited by selectively applying irrigation and fertilizer to different depths of soil in the field. When grown with grass, apple root growth increased at greater depths, resulting in greater uptake of ^{32}P at 90 cm depths (Atkinson and White, 1980). Atkinson (1980) reported that apple tree root growth increased in response to fertilization at depths from 50 to 80 cm under grass.

During the second growing season in Experiment 3, photosynthesis was very similar among apple trees grown with RB, TF, or without grass (Table 3). However, photosynthesis was significantly greater in apple trees that received irrigation and fertilizer at the 37-cm depth. This suggests that the deeply applied irrigation and fertilizer were being more effectively used by apple trees, possibly due to fewer grass roots (Fig. 3) or to greater apple RLD (Table 4) at the 20- to 40-cm depth. In the field, photosynthesis will likely decline more in trees grown with than without grass competition as found with peach (Tworkoski, 2000). This study and Atkinson and White (1980) suggest that providing resources such as water and fertilizer by subsurface irrigation may reduce adverse effects of USV.

Surface irrigation can compensate fruit trees for some water absorbed by grass (Layne and Tan, 1988; Merwin and Ray, 1997). We hypothesized that irrigation to depths below the rooting zone of shallow-rooted USV may provide water only to the fruit crop. In Experiment 3 of the current study, deep irrigation did not provide the water needed to support apple tree growth during the first growing season. However, during the second growing season the apple tree response was similar to irrigation at all depths, possibly reflecting acclimation of roots to soilless substrate patches that were enriched with water and/or nutrients as has been observed in peach trees (Tworkoski et al., 2003). In subsequent years, as would occur with production orchards, tree roots could further acclimate to watering regimes with roots proliferating near emitters. In this way deep roots could support water requirements of the trees.

Sustainable orchard practices must effectively manage resources for economical fruit production and to avoid degradation of the orchard ecosystem. Vegetation of the orchard floor can help maintain soil quality but it can compete for water and nutrients and host injurious insect pests and pathogens. In the first two experiments we demonstrated that RB was less demanding and less competitive with apple trees for water than TF. Less competition was associated with smaller and shallower grass root systems. Water limitations to apple trees could be obviated by irrigation at surface only or split to surface and 37-cm depths. These results suggest that grass cover of the floor of whole orchards may be a viable weed management tool, particularly if it is combined with selective irrigation and mowing.

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